Chip-Scale Energy and Power… and Heat

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
MAR 2009		**00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Flexibility for Ultra Low Power	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Virginia,Electrical and Computer Engineering Department,Charlottesville,VA,22904**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
MTO (DARPA Microsystems Technology Office) Symposium, 2009, Mar 2-5, San Jose, CA. U.S. Government or Federal Rights License

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**22**	

Flexibility for Ultra Low Power

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Sub-threshold (V_{DD}<V_T) Survey

- Sub-threshold benefits
  - Leakage Power Decreases: 5X to 90X
  - Energy Consumption Decreases: 10X to 20X
  - E_{total}/operation minimized in sub-V_T
  - Aging Effects Improve: NBTI, EM, TDDB
- Challenges
  - Lower I_{on} / I_{off}
  - Variation
- State of art
  - Logic, SRAM, arithmetic units, processors, simple systems

Key Remaining Problems for Sub-threshold Operation in Systems

1. Very slow
2. Best efficiency comes from ASIC, but costly and slow for new applications
3. Digital power a small piece of pie in many ULP systems

Outline

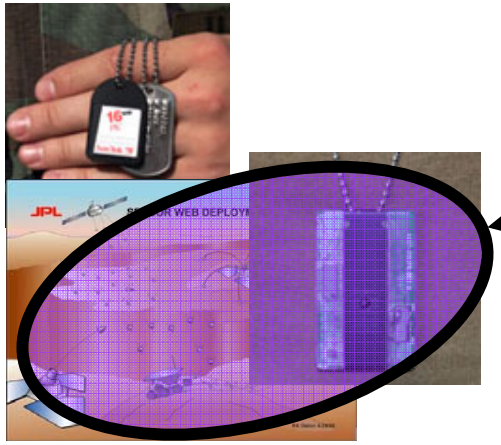
THESIS: Flexibility can help solve the key problems facing sub-threshold systems

- Energy / Performance Flexibility
- Hardware Flexibility
- System-Level Flexibility

“Low Power” Application Space

Portable Electronics, UAVs, UUVs, Comms, etc.
Workloads vary;
Maximize lifetime

Microsensors, physiological monitors, RFID, etc.
Energy Constrained



- **ULTRA Low Power:**
  Most Sub-V_T design, to date
  Minimize E/op; SLOOWW….

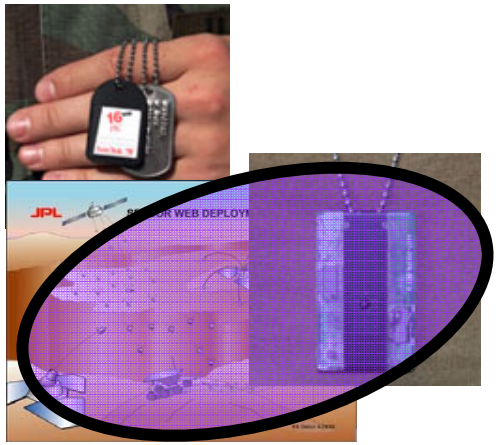
Power

Performance

“Low Power” Application Space

Portable Electronics, UAVs, UUVs, Comms, etc.
Workloads vary;
Maximize lifetime

Microsensors, physiological monitors, RFID, etc.
Energy Constrained

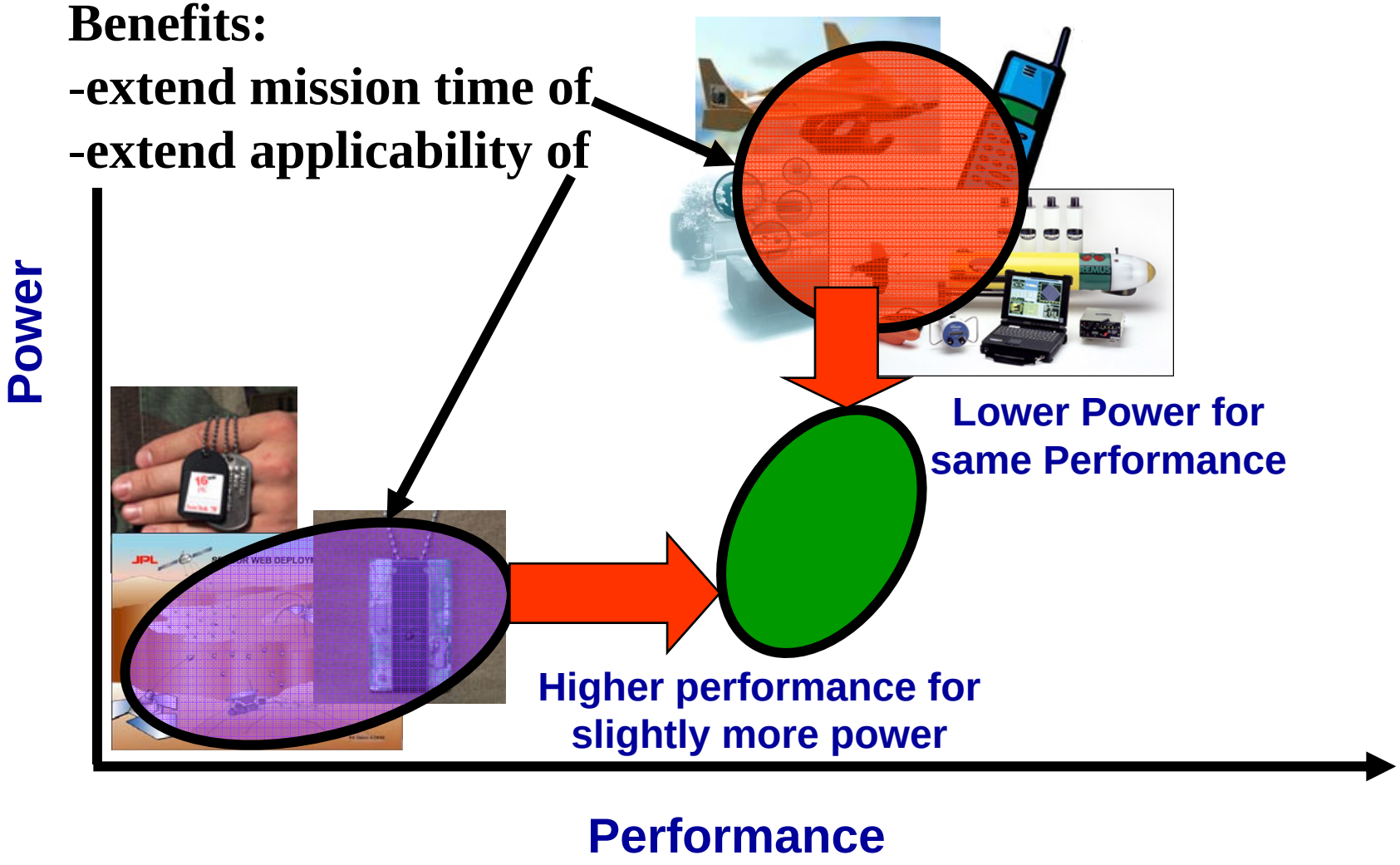


Power

Performance

■ **Portable Devices:**
Relatively high MAX performance;
Not ULP → Limited lifetimes

Proposed Energy/Performance Flexibility



How will we do this?

- Key insight: Definition of Performance

Old definition: Fixed speed or throughput

Accurate definition: Speed or throughput required to get "the job" done

"The job" changes:
→a range of performance requirements for a single app, depending on what is going on

Proposed Approach

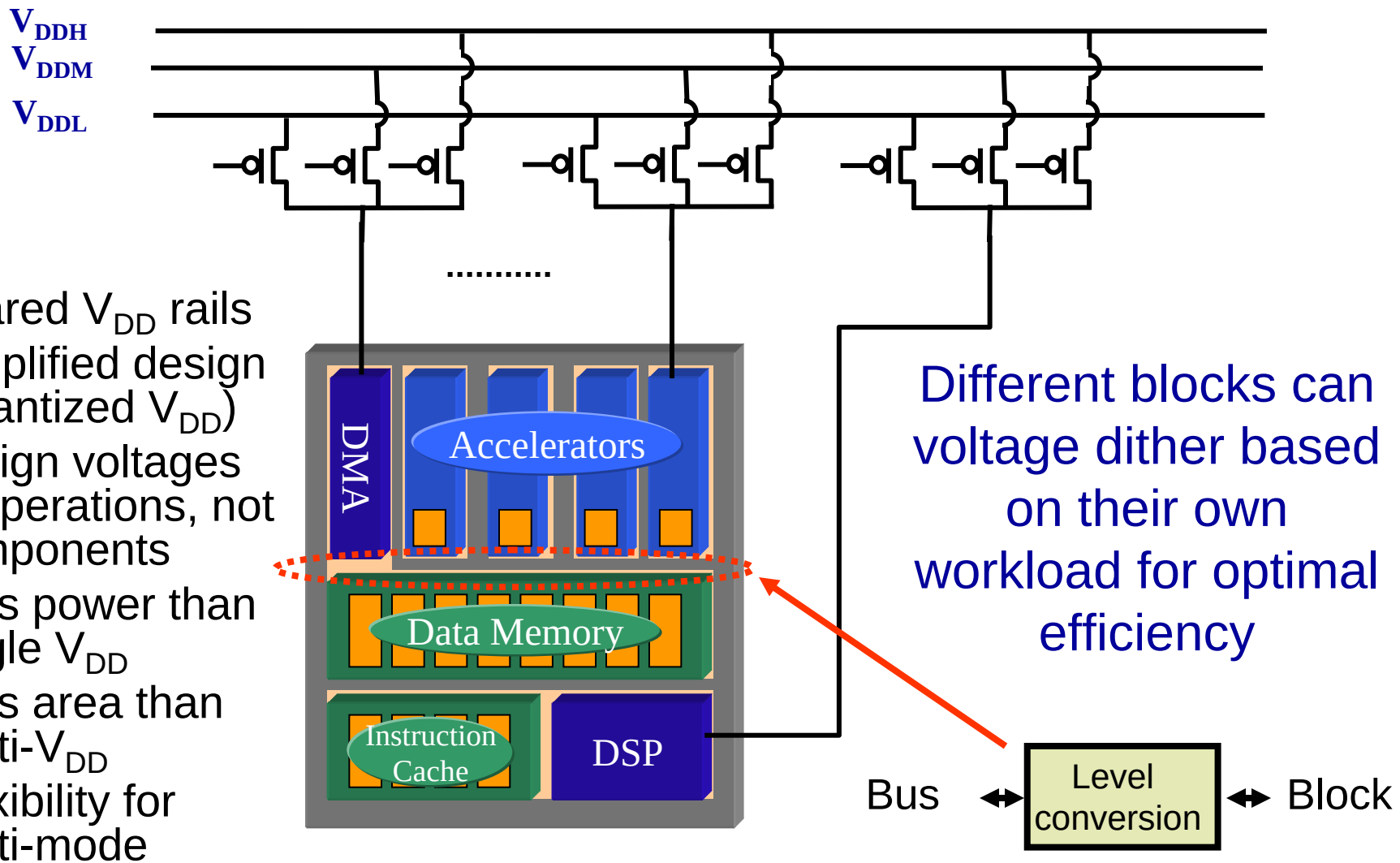
- Maximize efficiency of multi-V_{DD} design
  - Voltage is most effective knob

- Panoptic Dynamic Voltage Scaling (PDVS)
  - Multi-V_{DD}s (~2-4 voltage rails), local headers
  - Fully enables classical DVS
  - UDVS possible (hop to sub-threshold)
  - Finer *spatial* and *temporal* granularity
  - Multiple inherent power modes
  - Simple, low overhead implementation
  - LOTS of flexibility

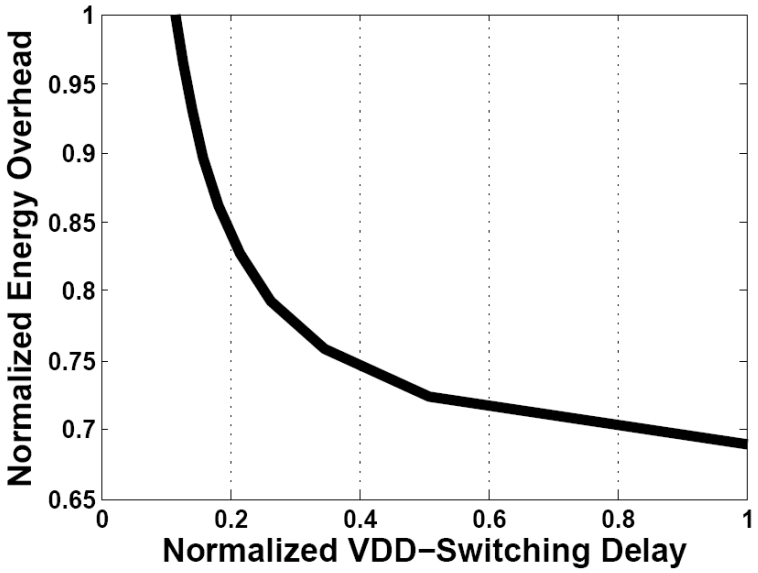
[with J. Lach (UVA, ECE)]

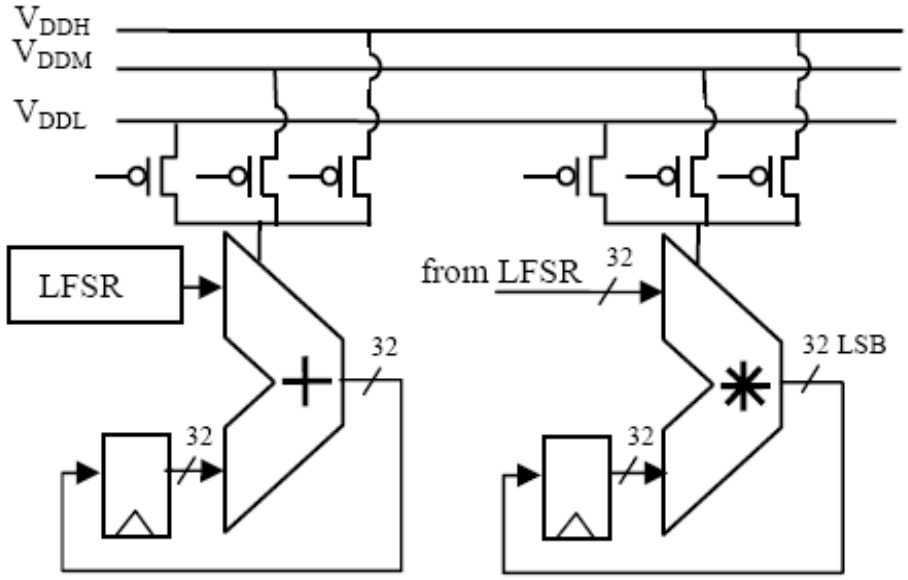
Example System: Apply PDVS to ASIC

- Shared V_{DD} rails
- Simplified design (quantized V_{DD})
- Assign voltages to operations, not components
- Less power than single V_{DD}
- Less area than multi-V_{DD}
- Flexibility for multi-mode



V_{DD}-switching energy





90nm Test Chip

Measured E overhead to find number of cycles at V_L to break even: < 1!!

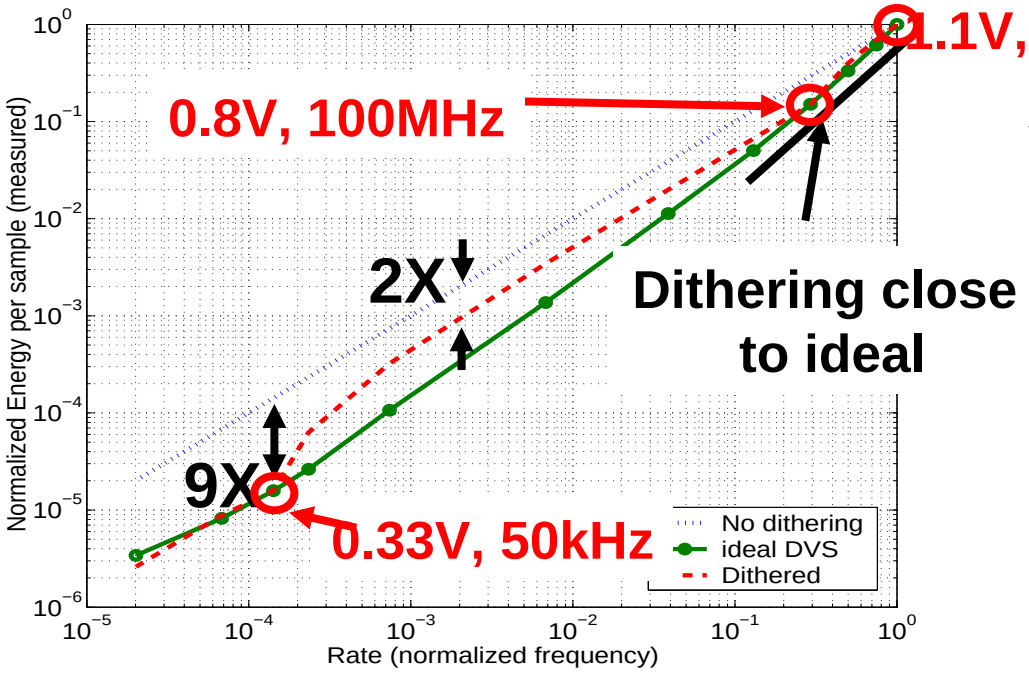
$$N_{BE} = \frac{(E_{High} - E_{Low})}{E_{switch}}$$

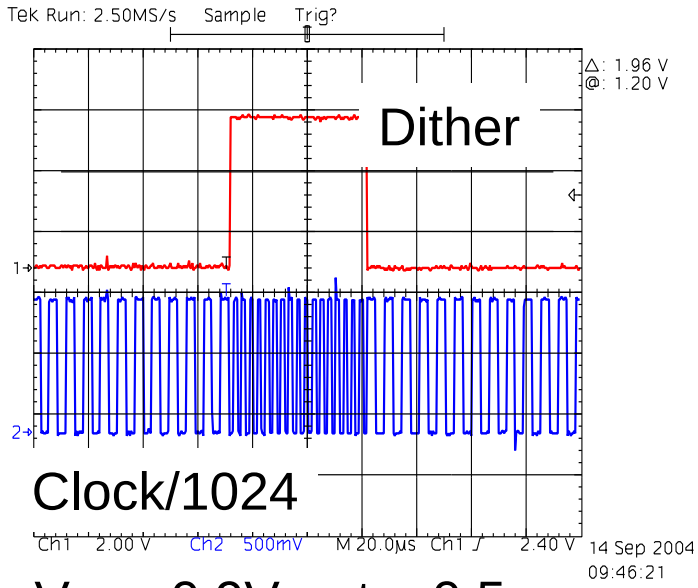
[ICCD, 2008]

Low Supply Voltage	Adder Break Even Cycles	Multiplier Break Even Cycles
0.9	0.689	0.436
0.8	0.579	0.408
0.7	0.607	0.263
0.6	0.721	0.328

UDVS: ULP (Sub-V_T) Option

Dither during high performance operation and switch to sub-threshold minimum energy operation when speed is not important





V_{DDL}=0.9V, rate=0.5

Calhoun & Chandrakasan, "Ultra-Dynamic Voltage Scaling Using Sub-threshold Operation and Local Voltage Dithering in 90nm CMOS," ISSCC, 2005.

Outline

- Energy / Performance Flexibility
- Hardware Flexibility
- System-Level Flexibility

The Problem: Many ULP Applications

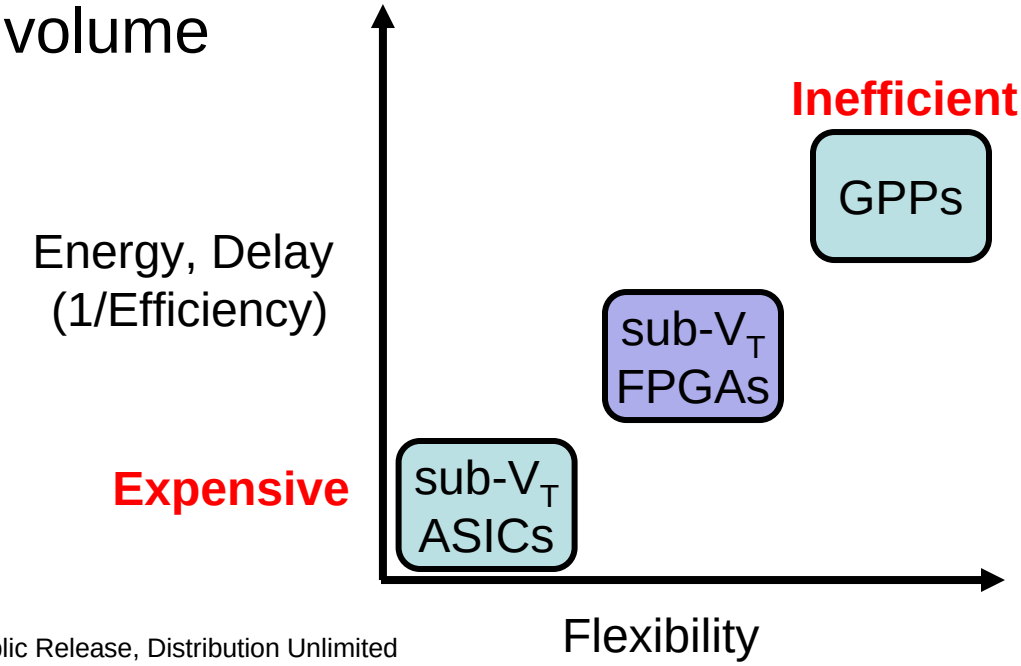
- Lots of apps (microsensors, RFID, tracking nodes, biotelemetry, micro-UAVs, hybrid insects, etc.)




  - Need ULP (sub-V_T) for feasibility
  - Economics: Often low volume

Sub-V_T FPGA:

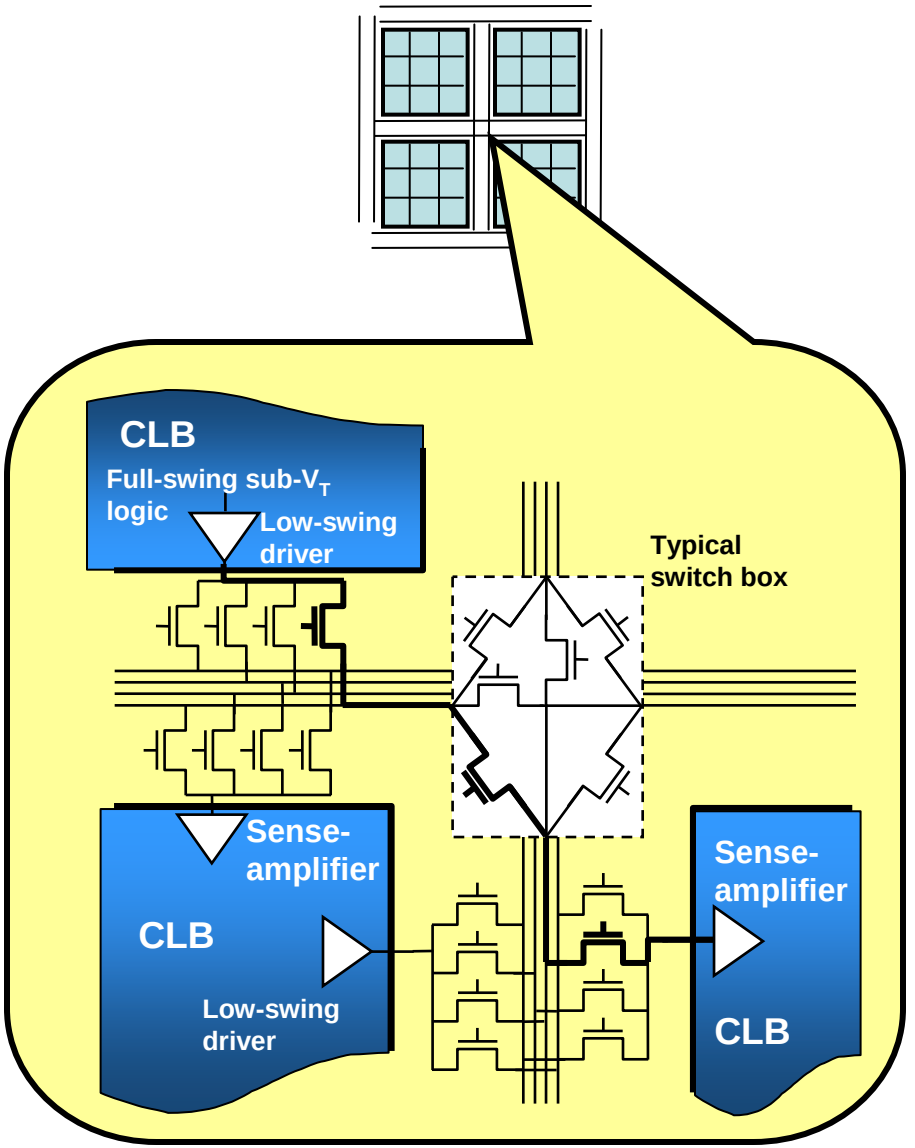
- Flexible, portable
- Low time-to-deployment
- Mission-specific efficiency
- Low unit cost



Ultra Low Power FPGA

- **Challenges to sub-V_T FPGA**
- **Variation, low I_{on}/I_{off}**
- **Interconnect dominates delay and power**

- **Approach**
  - **Low swing interconnect w/ sub-threshold sense amplifier**
  - **Regularity to reduce variation sources**
  - **Modified SRAM for config bits**
- **Anticipated Result**
  - **> 20X energy reduction**
  - **Tapeout spring 2009**



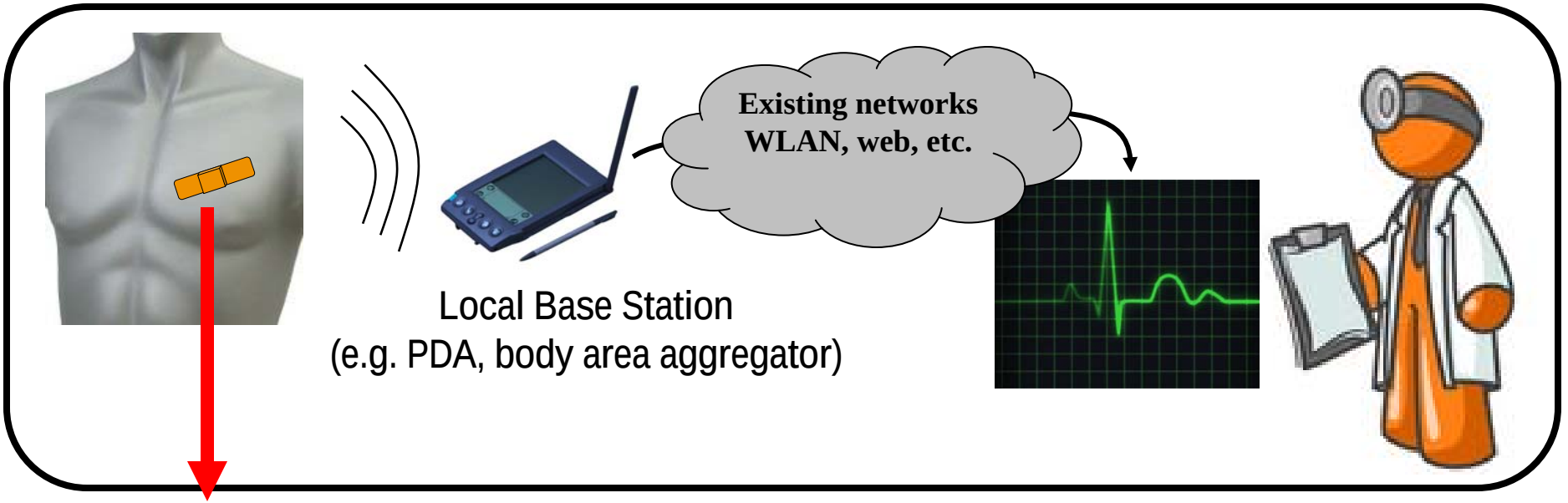
Outline

- Energy / Performance Flexibility
- Hardware Flexibility
- System-Level Flexibility

System Level Flexibility

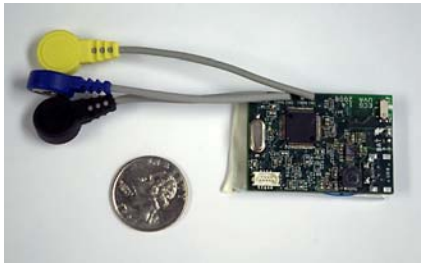
- Must consider system power breakdown
- Radio often dominates
- Leverage ULP digital (e.g. pre-process to reduce wireless data rate)
- Example system: ECG on a band-aid

Example: ECG Monitoring System



ECG sensing “patch”

- Analog Front end
- ADC
- Digital Processing
- RF TX/RX

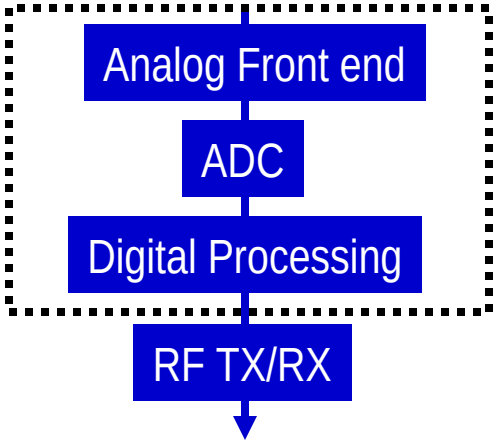


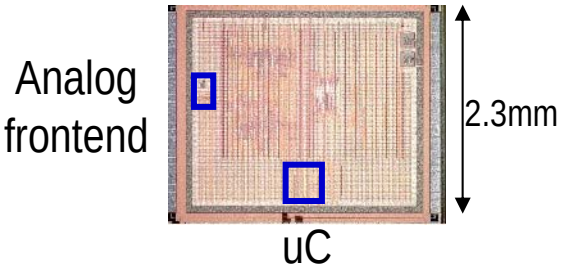
Discrete prototype

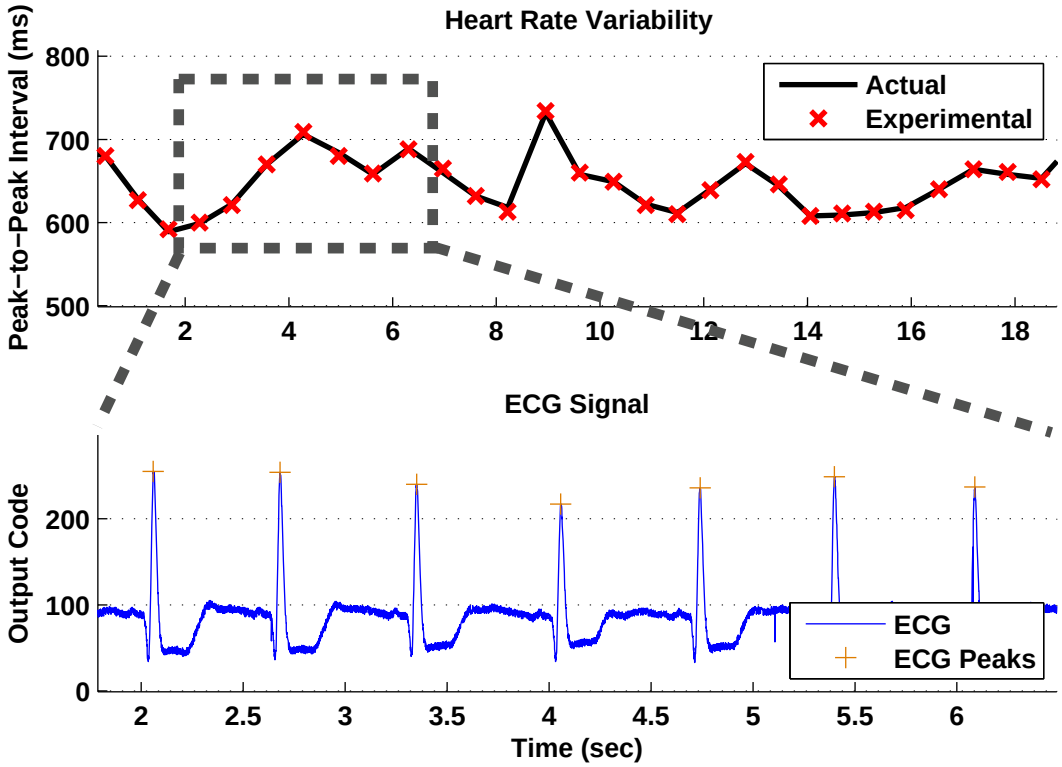
[with T. Blalock (UVA, ECE)]

Mixed Signal ECG System on Chip

ECG sensing “patch”







Leverage Sub-V_T processing by re-partitioning tasks at system level

Heart rate computation cuts wireless data rate by 500X

[with T. Blalock (UVA, ECE)]

Conclusions

- Flexibility solves key problems for sub-V_T systems
  - Energy/performance flexibility
  - Hardware flexibility
  - System flexibility

- Thank you! Any questions?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